A quick method of determining rock surface area for quantification of the invertebrate community

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Abstract

Stone and rock substrates provide important habitat for many types of stream-dwelling invertebrates. Measures of the invertebrate communities inhabiting rock substrates are often an important component of ecological, monitoring and disturbance studies in streams. A major obstacle to researchers examining rock-inhabiting invertebrates is the time and effort expended on currently used methods of determining rock surface area to derive invertebrate densities on these substrates. In an attempt to more efficiently determine invertebrate densities from rock substrates in streams, we tested a direct method of calculating rock surface area from rock weight or displacement volume. This method allows very quick determinations of rock surface area in the field. Surface area estimates made using this technique were highly correlated to those from a widely used and more time-consuming method. Measurements made using this new method should theoretically give better surface area estimates than any other commonly used technique.

Introduction

Investigations of the aquatic fauna inhabiting streams require a challenging treatment of the variety of substrate types, including rock and stone. Rock substrate has also often been introduced to many streams in regions where naturally occurring rock is absent or uncommon. Rock riprap is by far the most often used material for stream rehabilitation, erosion control and stability projects, accounting alone for more than 50% of all employed materials (Simons, 1995). Research by the National Sedimentation Laboratory (USDA-Agricultural Research Service) often includes examination of the benthic invertebrate fauna in streams where large amounts of rock riprap have been added. In our study area, introduced limestone rock is often the primary available stable substrate for benthic faunal colonization and merits study.

Biologists have striven for decades to devise more efficient and precise methods to study stone-dwelling invertebrates. Calow (1972) reviewed early methods of studying this fauna, and promoted the removal

of individual stones to obtain the most precise and realistic quantitative measure of the stone-dwelling community. Although this practice has been followed by researchers throughout the world (Carlsson et al., 1977; Dall, 1979; Gislason, 1985; Wrona et al., 1986; Morin, 1987; Lake & Schreiber, 1991; Payne & Miller, 1996), Calow (1972) and others (McCreadie & Colbo, 1991) have recognized the difficulty in measuring surface area of irregularly shaped stones.

Surface area estimates have been based on rock measurements such as length, width, height, perimeter and circumference. These estimates resulted from equations derived from calculations to determine surface areas of smooth shapes such as spheres, discs, blades and/or rods (Ehrenberg, 1957; Carlsson et al., 1977; Dall, 1979; Garga et al., 1991; Casey & Kendall, 1996). Some researchers have limited their representation of the natural environment by restricting rock selection to only rocks which shapes matched such equations. Even for other studies where rock selection was not biased and, in a few cases (Ehrenberg, 1957; Casey & Kendall, 1996) where some measure

of rock volume was used, the resulting surface area values likely did not truly represent the rock being studied as values were still calculated using equations developed for smooth-surfaced objects.

Alternatively, researchers used the weight of a coating applied to rocks to derive a surface area estimate through regression analysis. Surface coatings have been rubber latex and water (Calow, 1972), plastic food wrap (Doeg & Lake, 1981) and most recently, aluminum (tin) foil (Morin, 1987; Mackie, 1993; Tait et al., 1994). These methodologies allowed for more direct and precise quantification of actual stone surface area but were more tedious than estimates made using rock measurements. McCreadie & Colbo (1991) compared the foil wrapping technique to three measurement calculations for estimating stone surface area, and found that one slightly overestimated surface area while the two others greatly underestimated it.

New techniques have been developed to address the important problem associated with quantification of rock habitat area available for macroinvertebrates; specifically the manner of dealing with three-dimensional availability of rock surface area over two-dimensional bottom area (Wrona et al., 1986; Bailey et al., 1995; Downes et al., 1995). These newer techniques that more accurately determine invertebrate densities on stone substrates per unit of stream bottom area still entail an actual measurement of rock surface area by a method such as foiling or rock dimensions.

Direct mathematical regression (either linear or curvilinear) is often the simplest means of predicting a difficult to measure or unknown value from a more easily measured or known value. Faced with the task of quantitatively determining surface area for a large number of rocks during a basin-scale benthic invertebrate study, we tested a method for quickly and accurately estimating surface areas of rocks using a water displacement measurement that is easily made in the field. Our method provides equations for efficient and theoretically more accurate measurement of rock surface areas than any other published technique.

Material and methods

A selection of rock riprap of a variety of shapes and sizes representative of material used at local erosion control sites was taken from a construction site stockpile and transported to the laboratory ($n = 115$). Rock composition was limestone quarried from northeastern Mississippi. Rock shape was greatly varied and multi-faceted with numerous chinks and crevices, but individual facets were generally smooth. In the laboratory, individual rocks were numbered and weighed to the nearest 0.01 kg. The surface area of each rock was carefully measured using the foil-wrapping technique (Morin, 1987). A 19-l capacity plastic bucket was calibrated and marked in 0.25-l increments by addition of water. The bucket was then filled approximately half full of water, and the number of liters contained visually noted to the nearest 0.125 l. Each rock was then placed separately into the bucket and its displacement (to the nearest 0.125 l) was recorded after subtracting the original water-only measurement from that of the water and rock together.

Scatterplot graphing and regression of measured weight and displacement to foil-wrapping surface area estimates were fit to linear and polynomial (up to 6th order) mathematical equations using an intercept of zero, as no surface area would be expected at zero displacement. Although not allowing an intercept of zero, log, exponential and power equations were also fitted to the data to examine their suitability. Coefficients of determination (r^2) were then calculated to determine how much of the total variation was explained by each regression equation. Selected equations were used to predict surface area of larger stones than were actually measured, and the usefulness of these equations for such application was assessed.

Surface area measurements made using the foil wrapping technique were statistically compared to estimates generated from displacement measurements produced by selected predictive equations. Similar comparisons were made with a small number of available rocks of other compositions (sandstone from Lafayette County, Mississippi, USA, $n = 17$ and granite from glacial deposits, Wisconsin, USA, $n = 5$). Sandstone rocks used were generally flattened and tabular in shape, with long relatively large grooves or rills on their surfaces. Granite rocks used were spherical to disk-like in shape and had very smooth rounded surfaces. Data analyses and graphing were completed using SigmaStat® 2.0 (SPSS Science Corp.) and Microsoft Excel 97® software packages.

Results

Individual rock surface area measurements made using the foil-wrapping technique ranged from 309 to 2184 cm^2 (mean = 1006). Displacement volume of individual rocks ranged from 0.2 to 5.75 l (mean = 1.93).
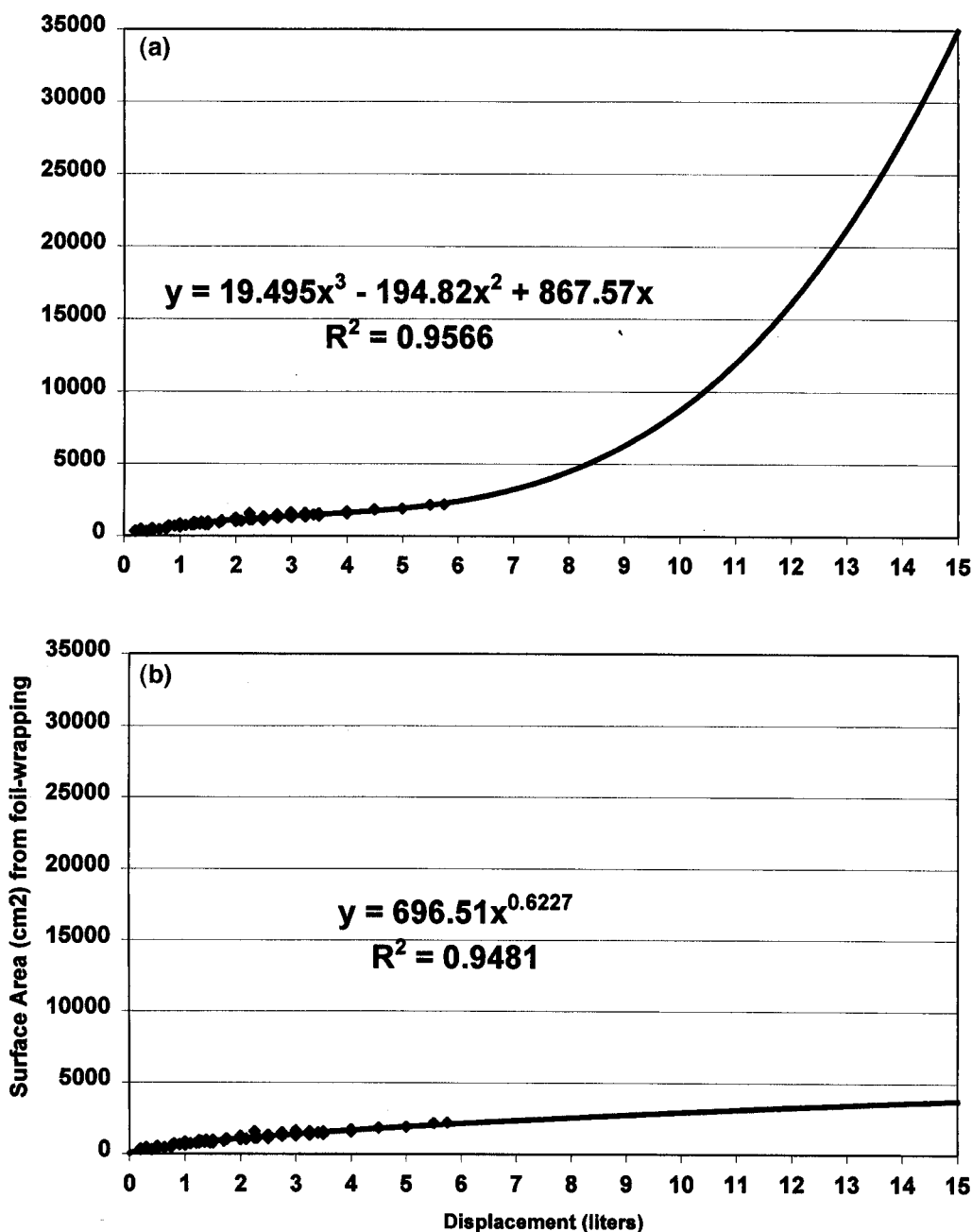
Figure 1. Scatterplot of rock displacement versus rock surface area measured using the foil-wrapping technique on limestone riprap. The trinomial equation was best suited inside the range of measured rock surface areas; however, the power equation proved nearly as useful within that range and appears better suited than the trinomial equation for estimating surface area of larger rocks (see text for explanation). $n = 115$.

Rock weights ranged from 0.57 to 13.8 kg (mean = 5.03). There was a highly predictive relationship observed between rock weight and displacement (linear regression, $r^2 = 0.9806$) and between rock weight and surface area measured by the foil-wrapping technique (power equation, $r^2 = 0.9774$).

The best regression of rock displacement values and surface area measured by foil-wrapping was observed using a 6th order polynomial ($r^2 = 0.9597$). Lower order polynomials gave only slightly poorer regressions ($r^2 = 0.9131$ to 0.9586), and the trinomial equation ($r^2 = 0.9566$) was nearly as suitable as the

Table 1. List of relationships evaluated for suitability in predicting surface area (y) of limestone riprap rocks, showing equations and associated coefficients of determination (r^2) for each. Larger coefficients of determination (r^2) indicate better predictive ability

Method	Equation	Predictive ability (r^2)	Comments/cautions
Rock Weight	Power; $y = 373.13x^{0.6367}$	0.9774	Very useful but requires equipment for weighing
Displacement	Polynomial (trinomial); $y = 19.495x^3 - 194.82x^2 + 867.57x$	0.9566	Works well within tested range but not suitable for projections
Displacement	Power; $y = 696.51x^{0.6227}$	0.9481	Works well, including for projections
Displacement	Log; $y = 550.71 \, \mathrm{Ln}(x) + 761.73$	0.8928	Not well suited to small or large observations
Displacement	Exponential; $y = 468.74 \, e^{0.3493x}$	0.8324	Not well suited to large observations
Displacement	Linear; $y = 473.38x$	0.7401	Accurate only for median observations

6th order polynomial (see Fig. 1). The power equation was also potentially useful ($r^2 = 0.9481$). The log equation provided only moderate predictive capacity ($r^2 = 0.8928$), and the exponential equation had even less value ($r^2 = 0.8324$). The linear equation gave the poorest predictions of surface area ($r^2 = 0.7401$). A comparison of tested equations is given in Table 1.

Comparisons of the surface area measurements made by the foil-wrapping method to estimates obtained from the trinomial or power equation indicate no significant difference exists between values obtained by the three methods (Kruskal–Wallis one-way ANOVA on ranks, $H = 0.00569$, $P = 0.997$, $n = 115$) for limestone riprap. Individual comparisons indicated no statistical difference between foil-wrapping method estimates and trinomial equation displacement-based estimates (Mann–Whitney rank sum test, $t = 13270.000$, $P = 0.981$, $n = 115$), nor between foil-wrapping estimates and power equation displacement-based estimates (Mann–Whitney rank sum test, $t = 13356.000$, $P = 0.885$, $n = 115$). Similar tests indicated that foil-wrapping measurements of surface area for sandstone rocks were not significantly different from values calculated from the trinomial equation (Mann–Whitney rank sum test, $t = 287.000$, $P = 0.731$, $n = 17$) or power equation ($t = 307.000$, $P = 0.757$, $n = 17$) derived for use with limestone. Although limited in scope and low in statistical power, similar results were obtained for the granite rocks when foil-wrapping measurement surface areas were compared to values calculated from their displacement using the trinomial (Mann–Whitney rank sum test, $t = 26.000$, $P = 0.841$, $n = 5$) and power equations (Mann–Whitney rank sum test, $t = 30.000$, $P = 0.690$, $n = 5$) derived for use with limestone.

Discussion

Based upon observed relationships, it appears that surface area estimates can be reliably made from known weights of limestone riprap rocks. If obtaining weights of similar rocks for a research project does not pose a problem, then use of the appropriate power equation provided in this manuscript should provide an accurate estimate of rock surface area.

While obtaining the weight of rocks in the field is feasible, determination of displacement is generally more easily done. When the researcher collects a rock to obtain invertebrates from its surface, the rock is

most often lifted into an awaiting bucket where it is brushed and washed to remove the invertebrates. The researcher may use this same bucket to obtain displacement values at the site if it has been calibrated. Thus, no additional equipment is needed (i.e., portable weight scales or balances), and the stones need not be taken outside the stream for a measurement to be made.

Although the 6th order polynomial equation showed the best predictive ability of all equations tested, polynomials over the third order are rarely used as predictive equations in the biological sciences (Sokal & Rohlf, 1981) for statistical reasons. The trinomial equation was better able to predict measured surface area than any non-polynomial type of equation tested here, and we recommend its use when rock displacement values fall within the limits of our study (0.2–5.75 l). However, the trinomial equation is not reliable for predictive projections above this range.

We derived an expected surface area value for a rock displacing a volume of 15 l from observed relationships between displacement and rock weight to surface area. This expected surface area (3853 cm^2) was very similar to that predicted by the power equation (3760 cm^2), and thus we suggest its use to provide estimates of surface area from displacement measurements above the limit of our study (greater than 5.75 l). If that area were estimated using the trinomial equation, a result of approximately 35 000 cm^2 (nearly an order of magnitude greater than that predicted by the power equation and from rock weight to surface area relationships) would be expected. We do not consider the trinomial equation's variation for large stones a critical failure of the concept since at higher values than we measured the power equation appears to be quite useful. Additionally, one reaches a point where manipulating a larger stone is dangerous or impractical, and in such cases biologists are more likely to simply sample a measured area.

Each investigator should test the suitability of this method to their specific circumstances using the variety of rock types, shapes and sizes encountered during their research study. We feel that the equations provided here will be useful to other researchers studying quarried limestone in the same size and weight category. Researchers who wish to study rocks of different composition, size or weight range should confirm the applicability of these equations to their material, or derive new equations suitable for their application. Although our methods are for determination of surface area estimates for whole rocks, research-

ers may use the same method for partially embedded rocks either by estimating the percentage of the rock that was not embedded or displacing only the portion that was not embedded (often easily discerned visibly after rock removal). Researchers should note that the displacement method is not aggregative, i.e., multiple rocks should not be submerged at once to obtain a single total displacement in an attempt to obtain the total surface area for the group of rocks. Also, the results obtained from the small number of sandstone and granite rocks provided in this manuscript suggest only a general indication of suitability of these equations to those types of rock.

Conclusion

Immediate on-site totals of surface area for common limestone riprap rocks can be produced with rock weight or displacement volume measurements and a handheld calculator. The relationship between rock surface area and displacement displayed through our research indicates that this technique can be used to facilitate field research for macroinvertebrate density estimation, as well as other applications (such as periphyton production calculations) where accurate surface area estimates are needed. This facilitates a more valid scientific comparison of substrate since some pre-determined or minimal quantity of surface area can then be sampled efficiently and with confidence. Because accurate surface area estimates of rocks can be achieved on site, there is no need to transport these heavy items from the site (which not only alters the habitat, but may also be illegal). Our method also eliminates the time consuming foil-wrapping method of measurement that is currently being widely used.

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